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Powering Our Community: An Analysis of Washington D.C.'s Renewable Energy Plan

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Introduction

"Fairy lights on a building that's supplying us power from the sea; Electricity lines flow like veins to the town" – Ed Sheeran, England

A standard internet search using any of the primary search engines for the term "renewable energy" brings back over eighteen thousand news articles published on July 16, 2024. Renewable energy is a massive part of everyday culture and will continue to be in the forefront of public discussion. The news cycle is inundated with talk of emergent technologies, plans to construct new power generation plants, and the dangers of not shifting the global sources of electricity. Many national and local governments are implementing plans to fund electricity generation from renewable sources and to reduce the effects of climate change caused by using nonrenewable energy sources. This is a massive undertaking, and the work required covers all facets of science, governance, and culture. And is far too complicated to cover in one curricular unit. However, by narrowing the focus to our local community's plan for shifting to renewable energy sources, we find an interesting intersection between science and connecting the classroom to the local community.

Washington, D.C., like many state governments, currently has a plan for making D.C. a very sustainable city that "balance[s] the environmental, economic, and social needs of the District of Columbia today as well as the needs of the next generation".[1] This plan covers a large variety of topics in 13 different areas of city government and uses both policy and infrastructure changes to achieve the goals within about 20 years. My curricular unit will focus on the renewable energy portion of that plan and guide students through an investigation on current methods of energy production. The energy portion of the Sustainable DC 2.0 plan has several goals, but I am focusing on Goal 2: "Increase the proportion of energy sourced from both clean and renewable supplies."

The sustainable energy plan for D.C. includes possible solutions and steps for implementing clean and renewable energy at all levels of society. There are options for home-based generation of electricity through small, rooftop solar panels or improving efficiency of household appliances. At a neighborhood level, larger solar or wind installations could be connected to centralize power generation for that area. This would allow specific areas that are not well-suited for renewable energy production to share resources with those that are well-suited. And finally at the district level, the efficiency and consistency of power generated from clean sources will be increased, creating a sustainable solution for many generations.

Demographics

I teach at Eastern Senior High School in Washington, D.C. and am the only physics teacher at the school. The students who enroll in my general education Physics I course are typically in the 11th grade, have taken biology and chemistry courses in the preceding years, and are not enrolled in I.B. sciences. Eastern is a neighborhood school in the District of Columbia Public Schools, which means that there is no application or academic criteria for attending the school. There is a variety of student skills and often the students that perform on-grade level will enroll in the I.B. science courses and not take physics. A majority of the students come from low-income families and often have deficits in their education before high school. The students demonstrate below-grade level math skills and so I reduce the amount of math used in physics, focusing more on a conceptual understanding. This unit will be designed for students in my high school physics class and will focus on the scientific concepts behind generating electricity, the efficiency of various processes, and the benefits of using renewable energies to power the local community.

Rationale

From a purely practical standpoint, electrical generation, magnetism, and electron flow are state standards for my students. This curricular unit will go much deeper than that. Renewable energy sources are frequently in local news, the topic of discussion for many cities and states, often a source of contention in local governments, and a necessary factor to combat global climate change. High school students will soon be adults in their communities and the next generation of leaders. Understanding the scientific concepts that drive renewable energy and the mechanics of how electricity is generated will ensure that students are able to identify misconceptions when participating in their communities.

This aligns to physics specific content through the exploration of the concepts behind electricity generation. Students will learn how solar cells use the sunlight to create a potential difference, powering an electric circuit and using that energy to generate work. From exploring the mechanics of wind turbines, students will achieve an understanding of electromagnetic induction. Both of these methods will also support the earlier learning of the laws of conservation of energy and mechanics of energy transformation, including efficiency and work to power ratios.

By incorporating local government officials into the classroom work, students will also learn how to be an active participant in their community and learn ways to improve the lives of those they care about through advocacy. This unit will not address political viewpoints but rather use renewable energies as the way to navigate a complex government and voice concerns about issues that are important. Government officials and community leaders who have contributed to the plan for sustainability will be invited into the classroom. Students can engage with them and discuss the specific choices made and how the local community will best benefit. Enabling students to be not just educated citizens, but active ones as well.

Finally, guiding students through an exploration of new topics and applying those concepts to the real-world examples will further develop students’ critical thinking. This is a skillset that is necessary for furthering their education and understanding of the world around the students. By modelling and experiencing appropriate strategies, students will be confident in applying those critical thinking skills to other topics of interest as they progress to active members and leaders of their community.

Content Objectives

Research and development of renewable energy has been prevalent in the science community for decades. Finding new, more affordable, safer, and more efficient ways to generate electricity can only improve society and can be a driving force for economic growth. Transitioning away from petroleum and coal is a major step in reducing the generation of greenhouse gases.[2] Because many municipalities, including Washington D.C., and companies are already taking steps to reduce their carbon footprint, reduce greenhouse gases, and attempt to slow global climate change, this curricular unit will not discuss the science and evidence for the effects of greenhouse gasses and global climate change. Our state and city government have the created the plan to achieve these goals, so we will focus on the steps they plan to take and understand the background concepts in the technologies proposed.

The plan for Washington, D.C. is titled *Sustainable DC 2.0* and has been in effect since 2013. A majority of state level governments in the United States have adopted a similar type of plan to increase the usage of clean energy and use renewable sources. Some specifics of the content included in this curricular unit are directly related to my community's sustainability plan, but can easily be adapted to any other plan. In D.C., seventy-five percent of the atmospheric emissions are a result of powering and temperature controlling buildings.[3] By working to transition to clean energy sources, ones that do not contribute to pollution and that have a net-zero carbon footprint, the district can drastically reduce its environmental impact.

The primary sources of renewable and clean energy generation specifically mentioned in the plan are solar energy, wind energy, and biogas fuels for heating and cooling. The background information presented in the next subsections will explore each of these in detail. Other renewable energy sources may be present in different localities, so if students wish to understand the details of those other sources, a research project would be an appropriate next step.

Solar Energy

One of the more accessible types of renewable energy is generating electricity directly from sunlight. Solar energy is available across the planet and does not have some of the same limitations as other forms of renewable energy. Sunlight strikes the Earth's surface at a staggering 173,000 terawatts of energy at any given moment.[4] This means that if we were able to harness all the energy, in less than two hours the total energy consumption for an entire year across the globe would be collected.[5] Unfortunately, current technologies for generating electricity from sunlight are not efficient enough to manage that, and it would be highly impractical to cover the entire surface of Earth with solar panels.

Figure 1: "Installation of solar PV panels - panels in place" by David Hawgood is licensed under CC BY-SA 2.0.

That said, there is a lot of energy that we can collect with solar panels and use to eliminate dependence on non-renewable sources of energy. There are two primary ways to collect solar energy and use it to generate electricity or store energy as heat. For the purposes of this curricular unit, I will be focusing on the photovoltaic process to generate electricity. Further research can be done to include concentrating solar-thermal power systems, but that is beyond the scope of my classroom.

The basis of photovoltaic solar cells originates from the discovery of the photovoltaic effect in 1839 by Alexandre Becquerel.[6] Becquerel discovered that an electrical current was created when plates of platinum and gold were exposed to sunlight while submerged in a solution.[7] From this discovery, other metals and solutions were tested and by 1883 the first true photovoltaic solar cell was created from selenium and a thin gold layer.[8] These early models were highly inefficient and did not create much of an electric current, but they set the stage for the scientific understanding of this effect and to improve on the process.

What is essentially happening in a photovoltaic solar cell is that when sunlight hits the metal an electron is excited and moves from the metal, creating a current. The reason this occurs lies in the materials used. Semiconductor metals must be connected in such a way that a p-n junction is formed.[9] A p-type semiconductor is one that has positively charged charge carriers, the opposite of an electron. Meanwhile a n-type semiconductor has charge carriers that are electrons. Placing these two types of semiconductors against each other will create the necessary p-n junction. When sunlight hits the n-type semiconductor, the electron charge carriers gain energy and break free of the molecular bonds. Since they are next to material with the opposite charge, an electric field is generated that moves these freed electrons further from the p-n junction. The positive charge carriers can also move further from the junction. The movement of oppositely charged particles increases the electrical potential difference, otherwise known as voltage, and creates a current once the photovoltaic solar cell is connected to an electrical circuit.[10][11]

The wide variety of possible semiconductor combinations to make a useful p-n junction means that a lot of research has been done to determine the most efficient in absorbing solar energy and the most cost-effective option. Almost all commercial solar cells today use crystalline silicon as both the n-type and the p-type semiconductors.[12] The process to make crystalline silicon allows for thin wafers to be created that can then be given opposite charges. Monocrystalline silicon has a singular crystal structure and is very efficient at allowing excited electrons to move through the silicon, increasing voltage and current in the system. This is by no means the only way that photovoltaic solar cells are made, and there is a lot of emerging research in other types of solar cells. Since this curricular unit will focus on what is currently available at a commercial level, the other types of semiconductors and research will not be discussed here.

There are scientific limitations on the efficiency of single silicon photovoltaic solar cells. When the high-energy photons of light strike the silicon and excite the electrons in the semiconductor, the greatest amount of usable energy is just above 30%.[13] The wavelengths of light transmitted from the sun match up to the energy levels that silicon will absorb to excite the electrons. Due to this physical limit, if 100 watts of sunlight where to strike the panel, it would only generate up to 30 watts of electricity. This is also a theoretical limit, so most commercially produced solar cells do not quite reach this highest level of efficiency. One way to combat this low efficiency is to simply connect together many single solar cells to make large panels and then connect those panels together. While the individual efficiency will not increase, covering a larger area will generate more electrical power.

Photovoltaic solar cells are not a perfect solution and will not fully replace all electricity generation in the near future. Solar cells naturally rely on direct sunlight, the more intense the better. There are many places across the world that do not receive as strong or consistent enough sunlight to generate the amount of electricity needed. Most locations also receive only twelve hours of sunlight a day, and photovoltaic solar cells cannot generate electricity at night. So, the solar cells generate electricity at inconsistent rates, and the demand of energy needed can often exceed what is being produced at a certain time. While it is technologically possible to transmit electricity generated in one area a long distance to where it is needed, that brings up new challenges. A more effective way to mitigate the issue of inconsistent generation from solar cells is to store excess energy for later use.[14]

Electrical power generation, and this is true for wind power as well, needs to match the demand at any given time. Electrical demand changes as the day progresses, and the locations where that electricity is being used changes. Overall, there is a lower demand through the late night and early morning and a higher demand in the evening. This means that electrical power generation needs to be able to fluctuate as the demand fluctuates. One limitation of solar power is that the generation of electrical power decreases as it gets later in the day, when the demand starts to increase. So there needs to be a way to efficiently store the excess power that is generated in the day and reintroduce it as the demand requires.[15]

There are methods of electrical energy storage, such as batteries, that work for small scale uses of solar cells. But batteries require the use of expensive metals and cannot currently be scaled up for power plant levels of usage. The largest energy storage technology is pumped hydro storage.[16] This method can store almost all of the electricity generated worldwide. The concepts are that the excess electricity generated is used to power a pump and move water to a physically higher reservoir. When the demand is greater than the generation of electricity, the upper reservoir of water is allowed to flow downhill and will generate electricity through hydroelectricity. There is some loss of energy through this process, up to 30% lost, but for areas that can have reservoirs at different altitudes it gives a very rapid source of electricity and storage.[17] Other large scale storage methods are possible and do work; the cost is just prohibitively high for widespread use.

Wind Energy

Another major source of renewable energy comes from wind-powered electrical turbines. The general basics of electricity generation have not changed since Faraday discovered induction in 1831.[18] What Faraday discovered is that a moving magnet inside a coil of wire will create, or induce, an electrical current in the wire. The inverse of this phenomena can be seen with electromagnetic devices. A moving charge, known as a current, can create or disrupt a magnetic field, allowing the magnet to turn off and on.[19] The only difference in non-photovoltaic electricity generation is what material is being used to turn the turbine. In non-renewable power plants, a resource such a coal is burned to heat water to steam and turn the magnet inside to generate electricity. A wind turbine uses the naturally occurring wind currents to spin a large set of blades that turn the magnet. The shape of the blades allows for a wider variety of wind speeds to turn the turbine and create electricity.[20]

Figure 2: "Cley Wind Mill" by Charles Greenhough is licensed under CC BY-SA 2.0.

Harnessing the power of the wind in order to achieve a goal is a very old process. From the earliest boats with sails to early windmills, humanity has been letting the wind spin an object for centuries.[21] The overall concept has not changed much in all of those years. Early windmills would pump water up to the surface, or certain devices could spin a series of mechanical gears to create motion. In areas where there is a significant and steady stream of wind, large turbines can be installed that turn a generator and create electricity. Wind farms, large areas with many turbines connected together, can be built both on land and offshore in the ocean and other large bodies of water.[22] Wind farms can vary greatly in size and in the amount of energy produced.

Wind is a naturally occurring phenomenon that happens when different temperatures and pressures of air collide.[23] The mixing of the air as it moves through the atmosphere is the wind that we feel on the surface of the Earth. There are a lot of variables that can affect how strong the wind is at a given location and how consistently through the year the wind blows. These variables also change the wind patterns as the altitude of the wind turbine increases.[24] A majority of land-based wind turbines for electricity generation are raised to about thirty meters above the ground, while offshore wind turbines can reach heights of 150 meters before including the length of the blades.[25]

Figure 3: "Wind Turbines" by John Webber is licensed under CC BY-SA 2.0.

Smaller wind installations can be used as well. Large wind farms are effective for powering a large geographic area, but small-scale energy generation can occur with what is known as distributed wind energy.[26] These systems are small scale and designed to power a building or small community. The current uses of this technology are low-energy equipment in remote locations, temporary installations in disaster relief efforts, and single building power generation.[27] The potential future uses of distributed wind energy can supplement the energy demands and reduce the cost to consumers when power is used.[28]

Similar to solar energy, wind energy is not perfectly constant and can experience periods of reduced electricity generation. Apart from raising the height of the wind turbine, the blades of the turbine are designed to spin faster at lower wind speeds. Long blades that have a slight twist can create a lifting force that improves the efficiency of the turbine spinning, generating more electricity from less wind.[29] Another way wind turbines can increase the efficiency is to be designed to rotate horizontally at the top of the turbine tower. The blades can point in the best direction to use the wind as efficiently as possible. This does add in a layer of complexity and potential mechanical failure, but the benefits in electricity generation outweigh this concern.

There are other drawbacks to using wind energy and building more wind farms. Often the sites where the strongest and most consistent wind can be found are remote. This brings challenges for construction and transmission of the electricity generated.[30] Offshore wind farms are a great example of this. The offshore wind farms can be more than 25 miles off of the coast in some areas[31] and the electricity generated then needs to be sent via underwater cables to where it can be used. Land-based wind farms can also experience this, particularly if the area that has the desirable wind patterns is in a mountainous or hilly area.[32]

Another drawback of wind energy is the environmental impacts. Wind turbines have an audible noise when spinning. This is less of an issue for offshore farms, but land wind farms can disrupt local communities and local wildlife by adding a near constant source of sound. There are also concerns on local populations of flying birds and insects. Having the large blades spinning at high speed will affect the wind currents that fauna has used to navigate the area, and may be a source of collisions with those animals.[33] Significant research is being completed to better understand the interaction between wind turbines and local wildlife, but the concerns and issues are still present.

The final primary drawback of using wind turbines to generate electricity is the same as a drawback with solar energy, storage. And here there is a possible point of overlap to using both systems at the same time. The storage options for excess energy generated by wind farms are the same as solar energy. Excess energy can be stored in battery systems or through methods such as pumped hydroelectric storage.[34] One benefit that storage from wind energy has over solar is that the amount of excess energy generated can be up to three times greater.[35] By investing in a storage solution at the grid level, rather than local small-scale storage like batteries, the amount of accessible energy should not ever be less than the demand.

Biogas

Another source of nonrenewable energy that contributes to greenhouse gases and global climate change is the use of natural gas for heating buildings and for cooking fuels. The issue with using a nonrenewable energy source such as natural gas is that the byproducts of burning that gas releases, mostly, carbon dioxide into the atmosphere that was stored.[36] Using a biogas as an alternative will result in net-zero carbon emissions as the carbon dioxide that is released originated from the atmosphere.

The creation of biogas can happen a few different ways and the exact gases that are generated depend on those processes. Primarily, biogas is a mixture of methane, carbon dioxide, and other trace gases that come from the chemical decomposition of organic matter.[37] This breakdown occurs in an anaerobic environment and does leave waste products that can be recycled into the system or has uses in agriculture.[38] The process of anaerobic digestion by bacteria occurs naturally and has been one way that organic matter reenters the environment. By creating systems and structures that encourage anaerobic digestion to occur and can capture the gases created, we now can harvest and use the methane and carbon dioxide for human energy needs.

A major source of the biogas currently in use is from landfills. Landfills take the local waste products and cover them with dirt. This creates the anaerobic environment that is necessary for bacterial digestion. The landfill is then equipped to gather the gases that are produced and transport them to be processed and used instead of natural gas.[39] Federal legislation requires that landfills that are large enough have a system to capture and control the gas emissions.[40] Sometimes this results in landfills that simply vent and burn the gas and do not use the biogas as an alternative fuel source. There are currently over 500 of these systems in use in the United States; however, landfills are one of the largest sources of methane production due to humans.[41] This capture system of methane emissions from local landfills has been used to generate energy. An example is the University of New Hampshire's (UNH) partnership with the Waste Management of New Hampshire in the city of Rochester. This partnership takes the captured methane from the landfill and is used as the primary fuel source in UNH's power plant, instead of natural gas. By using the local methane as the fuel, the greenhouse gas emissions and cost to operate the power plant have been cut drastically.[42]

Another method of generating and capturing biogas is in the form of an anaerobic digester. This is a container that is airtight and filled with organic materials and sometimes a starting bacteria culture to assist with the digestion.[43] The biogas produced is then collected and can be used interchangeably with natural gas. Often this system is used at agricultural and livestock facilities to digest the animal byproducts and crop residues.[44] Biodigester systems can be scaled for both large and small facilities, so the biogas produced could be used immediately at the location of generation with minimal processing.[45]

There are power plants that use this biogas, and biomethane, to directly generate electricity. These facilities can generate a significant amount of electricity; however, the uses of biogas for this curriculum unit are focused on heating and cooking.[46] The biogas that is produced from more commercial sources, landfills and agriculture, need to be processed before it can be used as a direct substitute for natural gas. Once the biogas has extra water vapor and carbon dioxide removed, it can be inserted into existing natural gas pipelines. This means that minimal updates to the current infrastructure are needed to use greater amounts of biogas.

Figure 4: "Methane capture power plant" by Alan Murray-Rust is licensed under CC BY-SA 2.0.

Biogas does have some limitations, some inherent and others as a result of economics. One issue it that some agricultural facilities have begun to grow crops solely for the use in energy production, and not as food.[47] Determining the best use of the land is a local issue that can lead to some serious consequences. Another concern with biogas is the danger of the flammable gasses. Methane, regardless of the source, can cause accidents in not only the generation and transport of the biogas but also at the end use of heating or cooking.[48] Finally, there are some concerns that the net reduction of greenhouses gasses has little room for error. Because methane is a potent greenhouse gas, if there is enough of a leakage of the biogas anywhere during the process, it is no longer clean and carbon-neutral energy.

Renewable Energy in Other Communities

The primary goal of this curriculum unit is to have students analyze the renewable energy plan for the local community. Other communities may choose to focus on alternative energy generation sources like hydroelectric power, solar thermal, biodiesel, or even nuclear power. Each of the other types of energy generation come with their own challenges and benefits. Further research may need to be completed to support student learning of these alternate energy sources. The most promising widespread future use and greatest increase in consumption of renewable energies in the past five years are what has been discussed above.[49]

Teaching Strategies

There are three primary sections for this curriculum unit and each section will focus on a different set of teaching strategies. The first section will focus on the scientific concepts and principles behind both renewable and non-renewable electrical generation. The second section of this curriculum unit will be on the non-scientific considerations for renewable energies. The final section of the curriculum unit is the analysis of D.C.'s clean energy plan.

Guided Readings and Lectures

To begin to understand the basics of power generation, students will learn through lecture and guided readings, or videos, the history of magnetic induction and processes that govern nonrenewable power plants. The notes and readings will give students a reference for the later explorations of renewable energy. The climate and ecological impact of nonrenewable energy will be discussed so students understand why governments and society are transitioning to renewable energy.

Hands-On Activities

In order to investigate renewable energy sources and understand the scientific concepts present, students will have hands-on laboratory investigations. In these investigations, students will generate electrical power through solar cells and miniature wind turbines. Hands-on laboratory experiences are vital for making abstract concepts, such as electricity generation, tangible and relatable to the students' schema. This hands-on exploration will guide students through understanding the differences between how these processes create electricity and the limitations and efficiency of both. Once students have completed the hands-on laboratory work, they will compare research of the large-scale versions of the renewable energy sources that are outlined in the plan for D.C.'s sustainable future to compare how their investigations match the published literature.

Guided Research and Guest Speaker

The second section of this curriculum unit will be on the non-scientific considerations for renewable energies. This includes cost, infrastructure needed, land use, and other factors that local governments must consider when determining how to generate the electricity needed. Students will complete small research projects on what these factors are in our community and present their findings to the rest of the class. The research projects will have teacher-created requirements for consideration, but the students can also choose to further the research. Resources will be provided to assist in finding appropriate sources. This is also where students will discuss with local government officials and community leaders on why one source of renewable electricity generation may be better than another, and what other factors those officials must consider when crafting a plan. Students will be provided with literary sources and will develop questions to ask the local officials, either in person or remotely. If no local officials or community leaders are available to speak with the students, then other research will be completed to find and understand the limitations present in deciding what renewable energy sources are appropriate for our community.

Literature Analysis and Proposal

The final section of the curriculum unit is the analysis of D.C.'s clean energy plan. From the information learned in the first two sections, students will create criteria that they wish to evaluate the plan against. This could include cost, efficiency, impact on the environment, and accessibility of non-renewable energy sources. After students have created their criteria and a ranking system, they will then research and explore the publications available for the current city sustainability plan. After scoring the city's plan, students will prepare a short presentation on how well the plan meets the criteria that they chose, and will include recommendations for how to improve the plan in order to match what the students view as a best-case scenario. If possible, these presentations would happen in front of the class and local government officials and community leaders, but that might not be realistic due to scheduling constraints.

Classroom Activities

Hands-On Activities

When teaching scientific concepts, I find it most effective to begin with a hands-on investigation of the concept before explaining the laws, theories, and equations that govern those concepts. To introduce this unit on renewable energy sources, I will start with an exploration of electromagnetic electricity generation. Students will be given an exploration sheet that has experimental steps and guiding questions. They will use copper wires, a bar magnet, and a small lightbulb to create a working circuit. Students will use the magnet with the copper wires to generate an electrical voltage that will be visible with the lightbulb. Data will be taken on voltage and current for students to analyze and compare the number of wire loops to the voltage produced.

After a classroom discussion and explanation of Faraday's laws, students will explore wind powered turbines. A wind-powered generator kit can be purchased online, or built with fairly common materials. Students will complete a circuit with the wind-powered generator as the voltage source, an ammeter, a voltmeter, and a lightbulb. Students will use a constant supply of wind from a household fan to test different blade lengths and shapes on the generator. Data will be collected, and students will determine what makes a wind turbine spin the most efficiently to generate electricity.

The final hands-on exploration for this curriculum unit is to investigate photovoltaic solar cells through racing solar powered cars. Solar car kits can be purchased online or built with household materials and a photovoltaic solar cell with a small motor. Students will first determine how large of a solar cell to use with their car. Given two or three options of size and mass, students can determine how much voltage is produced in natural sunlight and select the combination they believe will create the winning car. After building their car, groups of students will race outside to see what combination was the most successful. Students will then complete an analysis sheet that connects the photovoltaic cells on the small-scale cars to the larger cells used for widespread electricity generation.

Guided Readings

To connect the hands-on activities to the guiding scientific concepts, students will complete a series of guided readings between the laboratory investigations. These guided readings will serve as a reference document for students to use when analyzing the Sustainable D.C. 2.0 plan. The readings will be supported by some direct instruction if needed. There are a number of high-quality sources for readings that cover the scientific concepts well, I will use resources from the University of Wisconsin Stevens Point as the readings have well developed images and are accessible at various levels of reading ability.[50] Between each of the laboratory investigations, students will annotate the readings, answer guided questions, and create a graphic organizer for each type of renewable energy. The readings should focus on the scientific principles that allowed for renewable energy generation to be large-scale and emerging technologies that will improve renewable energy generation.

Literature Analysis and Research

Students will complete a literature analysis of the Sustainable D.C. 2.0 plan and make a recommendation for changes to the plan. In order for students to complete this analysis, they will need to first analyze the plan and then complete other research to understand the cost and efficiency constraints with the selected sources of energy generation. Students will work in groups to summarize the current plan for D.C. and identify the sources of energy generation. Once students understand the Sustainable D.C. plan, they will create a presentation making a recommendation on how to improve the plan and support renewable energy generation in their community. Student presentations must include a cost to benefit analysis and a scientific justification for why their recommendation reduces the emission of greenhouse gases.

In order to fully analyze the local sustainability plan, students may need to do independent research. This research will be guided with specific points to identify and an annotated bibliography to support the claims made. Students may need assistance identifying peer-reviewed sources and quality information from online information. Many high-quality resources can be found through local or state departments of energy and outreach programs.

Resources

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Department of Energy. 2016. *Top 6 Things You Didn't Know About Solar Energy.* Accessed July 16, 2024. https://www.energy.gov/articles/top-6-things-you-didnt-know-about-solar-energy. – This website is a great resource for undertanding the basics of solar energy production.

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Appendix on Implementing District Standards

Washington D.C. uses the Next Generation Science Standards as the framework for the high school science courses. These standards have many applicable statements, including the Science and Engineering Practices and Crosscutting Concepts. I will focus on the topic standards. Standard HS-PS1-3 Matter and its Interactions is the first that applies. Students will use the voltage generated from Faraday's Law and the photovoltaic solar cells to determine the electrical strength between the particles, specifically, when using the electrical field to move a motor.

The second applicable standard is HS-PS2-5 Motion and Stability: Forces and Interactions. Students will use a changing magnetic field to generate an electrical current. The students will collect data and explore how the variables in a changing magnetic field will increase or decrease voltage produced. These standards also connect to common core standards for English and Literacy, as well as mathematics.[51] In the context of a high school introductory course, this curriculum unit could be a culminating unit that incorporates many concepts throughout the year and those concepts that are typically more advanced and implemented at the end of the academic year.

Notes

[1] https://sustainable.DC.gov/sD.C.2

[2] Goldstein-Rose, p. 84

[3] https://sustainable.dc.gov/page/energy

[4] https://www.energy.gov/articles/top-6-things-you-didnt-know-about-solar-energy

[5] https://www.energy.gov/eere/solar/how-does-solar-work

[6] Fraas, Lewis, and Mark O'Neill p. 2

[7] Palz, p. 6

[8] Palz, p.8

[9] https://energyeducation.ca/encyclopedia/Photovoltaic_effect

[10] https://energyeducation.ca/encyclopedia/Photovoltaic_effect

[11] Fraas, Lewis, and Mark O'Neill p. 4

[12] https://energyeducation.ca/encyclopedia/Photovoltaic_effect

[13] https://energyeducation.ca/encyclopedia/Photovoltaic_effect

[14] Blakers, p. 197

[15] Brudvig, Gary. "Energy: Past, Present, and Future". Lecture, Yale University. July 16, 2024.

[16] Blakers, p. 197

[17] Blakers p. 198

[18] https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php

[19] Williams p. 28

[20] https://www.nrel.gov/research/re-wind.html#:~:text=Unlike%20fans%2C%20which%20use%20electricity,generator%20and%20creates%20clean%20electricity.

[21] https://www.nrel.gov/research/re-wind.html#:~:text=Unlike%20fans%2C%20which%20use%20electricity,generator%20and%20creates%20clean%20electricity.

[22] https://www.nrel.gov/research/re-wind.html#:~:text=Unlike%20fans%2C%20which%20use%20electricity,generator%20and%20creates%20clean%20electricity.

[23] Jaffe, p. 551

[24] https://windexchange.energy.gov/maps-data

[25] https://www.energy.gov/eere/wind/articles/top-10-things-you-didnt-know-about-offshore-wind-energy

[26] https://www.nrel.gov/wind/distributed-wind.html

[27] McCabe, p. 4

[28] McCabe, p. 4

[29] https://www.energy.gov/eere/wind/articles/top-10-things-you-didnt-know-about-offshore-wind-energy

[30] Jaffe, p. 552

[31] Sullivan, p. 3

[32] Jaffe, p. 540

[33] https://windexchange.energy.gov/projects/wildlife

[34] https://climate.nasa.gov/news/1055/study-wind-farms-can-store-and-deliver-surplus-energy/

[35] https://climate.nasa.gov/news/1055/study-wind-farms-can-store-and-deliver-surplus-energy/

[36] Solomon-Goldstein. P. INSERT

[37] https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

[38] https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy

[39] https://afdc.energy.gov/fuels/natural-gas-renewable

[40] https://www.eia.gov/energyexplained/biomass/landfill-gas-and-biogas.php

[41] https://afdc.energy.gov/fuels/natural-gas-renewable

[42] https://www.unh.edu/sustainability/ecoline

[43] https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-t

o-biogas-and-biomethane

[44] https://afdc.energy.gov/fuels/natural-gas-renewable

[45] https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy

[46] https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

[47] https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

[48] https://blogs.edf.org/energyexchange/2019/04/15/not-all-biogas-is-created-equal/

[49] https://www.eia.gov/totalenergy/data/monthly/pdf/sec10_3.pdf

[50] https://www.uwsp.edu/wcee/wcee/keep/keep-lessons/renewable-energy-lessons/

[51] https://www.nextgenscience.org/pe/hs-ps3-5-energy